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Factor analysis of pesticide use patterns among pesticide applicators in the Agricultural Health Study

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Exposure to certain pesticides has been linked with both acute and chronic adverse health outcomes such as neurotoxicity and risk for certain cancers. Univariate analyses of pesticide exposures may not capture the complexity of these exposures since use of various pesticides often occurs simultaneously, and because specific uses have changed over time. Using data from the Agricultural Health Study, a cohort study of 89,658 licensed pesticide applicators and their spouses in Iowa and North Carolina, we employed factor analysis to order to characterize underlying patterns of self-reported exposures to 50 different pesticides. Factor analysis is a statistical method used to explain the relationships between several correlated variables by reducing them to a smaller number of conceptually meaningful, composite variables, known as *factors*. Three factors emerged for farmer applicators ($N = 45,074$): (1) Iowa agriculture and herbicide use, (2) North Carolina agriculture and use of insecticides, fumigants and fungicides, and (3) older age and use of chlorinated pesticides. The patterns observed for spouses of farmers ($N = 17,488$) were similar to those observed for the farmers themselves, whereas five factors emerged for commercial pesticide applicators ($N = 4,384$): (1) herbicide use, (2) older age and use of chlorinated pesticides, (3) use of fungicides and residential pest treatments, (4) use of animal insecticides, and (5) use of fumigants. Pesticide exposures did not correlate with lifestyle characteristics such as race, smoking status or education. This heterogeneity in exposure patterns may be used to guide etiologic studies of health effects of farmers and other groups exposed to pesticides.
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Introduction

Factor analysis has been increasingly used in epidemiologic studies to examine relationships such as dietary factors and breast cancer risk (Lubin et al., 1981; Terry et al., 2001), patterns of metabolic factors and heart disease (Marusic, 2000), and environmental factors associated with prevalence of acute respiratory infection in children (Gupta et al., 1999). Factor analysis is a statistical method used to explain the relationships between several correlated variables by reducing them to a smaller number of conceptually meaningful, composite variables, called *factors* (Kleinbaum and Kupper, 1978). These factors may be used as independent or dependent variables in subsequent analyses, and may be used to guide subsequent analyses. Therefore, factor analysis is often used in conjunction with more traditional statistical methods such as regression analysis.

Using data from the Agricultural Health Study (AHS), a prospective cohort study of licensed pesticide applicators and their spouses in Iowa and North Carolina, we employed factor analysis to examine the underlying patterns of self-reported exposures to 50 pesticides. Exposure to certain pesticides has been linked with both acute and chronic adverse health outcomes such as neurotoxicity and certain types of cancer (Zahm et al., 1997). Two important factors that make pesticide exposure assessment difficult are that use of various pesticides often occurs simultaneously, and that pesticide products registered for specific uses have changed over time. Therefore, characterizing patterns of exposure may provide additional insight into disease occurrence than evaluating single exposures.

Three types of applicators were enrolled into the AHS cohort: farmer applicators, spouses of farmer applicators, and commercial applicators. Each group provided information on use of the same 50 pesticides. Since the types of application activities may vary between farmer and commercial applicators, and may vary between farmers and their spouses, we performed separate analyses for each group.

Methods

The Agricultural Health Study has been described elsewhere in detail (Alavanja et al., 1996). Briefly, the Agricultural

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Health Study is a prospective cohort study of 57,311 licensed pesticide applicators (including 52,395 farmer and 4916 commercial applicators) and 32,347 spouses of farmer applicators in Iowa and North Carolina. Farmer applicators and spouses were enrolled from both states, while commercial applicators were enrolled only from Iowa. Data were collected by means of a self-administered questionnaire given at study enrollment. The enrollment questionnaire sought information concerning use of various pesticides, pesticide application methods, use of personal protective equipment, types of crops and livestock raised, smoking and alcohol consumption, medical history, diet, as well as basic demographic information. Recruitment into the cohort began in December 1993 and continued through December 1997. Questionnaires may be obtained from the following website: http://www.aghealth.org.

In the enrollment questionnaire, farmer and commercial applicators were asked to provide detailed information on their use of 22 pesticides, including frequency (average number of days per year used), duration (total number of years used), and the decade when they first starting using the pesticide. For an additional 28 pesticides, exposure was reported in terms of ever/never use. Farmer applicators were also given questionnaires for completion by their spouses. Spouses were asked to report whether they had ever used any of the same 50 pesticides during their lifetimes. In general, pesticides are substances used to destroy or prevent any pest, including insects, animals, weeds, fungi, molds and bacteria. While insecticides specifically target insect pests, herbicides are used to destroy weeds or other plant pests, and fungicides and fumigants target fungi and mold. The group of 50 pesticides evaluated in this analysis included 18 herbicides, 22 insecticides, four fumigants and six fungicides.

In order to include all 50 pesticides in the factor analysis, and to compare results between applicators and spouses, reported use of the 50 pesticides was scaled as ever = 1 or never = 0. Other variables included in the analysis were demographic variables for state of residence (0 = North Carolina, 1 = Iowa), subjects over 50 years of age at enrollment ($0 = \leq 50$, $1 = > 50$), and gender (0 = female, 1 = male).

In addition to questions about specific pesticides used, farmer applicators were asked detailed questions about their farm activities and pesticide application practices, which allowed us to perform additional analyses to determine whether any of the following would cluster with pesticide use: types of crops grown or livestock raised; methods of pesticide application generally employed; protective equipment generally used while applying pesticides, and lifestyle characteristics such as smoking and alcohol consumption. Variables for types of crops included the following: field corn, sweet corn, soybeans, cotton, peanuts, tobacco, Christmas trees, strawberries, peaches, other fruit (apples, blueberries, grapes, watermelon, and other fruits), other vegetables (alfalfa, cabbage, cucumbers, green peppers, potatoes, snap beans, sweet potatoes, tomatoes, and other vegetables), and grains (hay, oats, sorghum, wheat, and other). Six livestock variables included beef cattle, dairy cattle, poultry, sheep, eggs, and hogs. There were 11 variables for herbicide or crop insecticide application methods: aerial, airblast, backpack spraying, tractor boom, hand spraying, in furrow or banded application, mist blowing, row fumigation, pouring fumigants from a bucket, use of a gas canister, and powder dusting. Two additional variables for crop pest control methods were use of granules/tablets and planting pretreated seeds. Animal insecticide application methods included spraying animals, dipping animals, applying ear tags, and injecting animals. Types of personal protective equipment generally used while applying pesticides included use of chemical gloves, use of fabric gloves, wearing disposable clothing such as Tyvek®, use of a face shield or goggles, use of a respirator or face mask, and none. We also included the following six lifestyle variables: smoking status (ever/never), race (white/non-white), education (less than high school/high school or higher), fruit consumption (1 or more per day/less than 1 per day), vegetable consumption (1 or more per day/ less then 1 per day), and alcohol consumption (1 or less per week/more than 1 per week).

All analyses were performed using Statistical Analysis Software (SAS Institute, 2001), using the principal axis factoring method (PROC FACTOR). With this method, *factors* were extracted, or derived, in descending order of importance with respect to the proportion of variance in the observed data accounted for by each factor (Hatcher, 1994). For example, the first factor derived is the weighted linear combination of the variables which accounts for the largest total variation in the data (Kleinbaum and Kupper, 1978). No other linear combination of variables should have as large a variance as the first derived factor. The second factor derived accounts for the largest proportion of the remaining variance not accounted for by the first factor, and so on.

Each variable included in the analysis contributes one unit of variance to the total variance in the data set. The *eigenvalue* associated with each factor represents the amount of variance accounted for by that factor. The sum of all eigenvalues equals the total number of variables in the dataset. An eigenvalue less than 1.00 indicates a factor that accounts for less variance than a single variable. Since the goal of factor analysis is to reduce a large number of variables down to a relative small number of summary factors, it is not efficient to retain factors that account for less variance than what was contributed by the original variables. An eigenvalue greater than 1.00, however, indicates a summary factor that accounts for a greater amount of variance than had been contributed by one variable.

A *factor loading score* was calculated for every variable in every factor. Factor loading scores represent the correlations between each of the variables included in the analysis and each summary factor, and are equivalent to Pearson correlation coefficients (Hatcher, 1994). Ideally, few variables in each factor will have a factor loading score above a certain value that is specified prior to analysis. In general, for exploratory analyses, factor loading scores are considered to be meaningful when they exceed ± 0.30 or 0.40 (Floyd and Widaman, 1995). Since this was an exploratory technique we selected ± 0.40 or higher, in order to be more discriminating. The initial factor analyses performed for farmer applicators, their spouses, and commercial applicators included the 50 pesticide variables, age, gender, and state (state was not included for commercial applicators because all were from Iowa).

After initial extraction, factors were rotated to aide interpretation. We employed oblique rotation to allow for some degree of correlation among the newly derived factors. Since pesticide and farming activities may change over time, we assumed that farmer's activities may be described by more than 1 factor. *Rotation* may be defined as a linear transformation performed on the initial factors, with the goal of simplifying the factor structure, so that each variable will load on as few factors as possible (Gorsuch, 1983). In simpler terms, rotation simplifies the factor patterns so that the variables in each factor with high factor loading scores are different for each factor, yielding distinct groupings of variables that are used to interpret the factors.

To determine how many factors to retain we applied the following criteria: there must be at least three variables in the factor with a high factor loading score (± 0.40 or greater); factors must have an eigenvalue greater than 1.00; and each factor must account for at least 5% of the total variance. Ideally, the number of retained factors will be small, and will explain the majority of the variance in the observed data (Floyd and Widaman, 1995).

Table 1. Characteristics of licensed pesticide applicators and spouses in the Agricultural Health Study cohort (1993–1997) included in the study

Characteristic	*Applicators*		
	Farmer (%) $N = 45{,}074$	Commercial (%) $N = 4384$	Spouses (%) $N = 17{,}488$
State			
Iowa	29,277 (64.9)	4384 (100)	12,791 (73.1)
North Carolina	15,797 (35.1)		4697 (26.9)
Age (years)			
<40	14,199 (31.5)	2588 (59.0)	4670 (26.7)
40–50	13,631 (30.2)	1184 (27.0)	5931 (33.9)
>50	17,240 (38.2)	612 (14.0)	6887 (39.4)
Not reported	4 (<1.0)		
Gender			
Female	1120 (2.5)	204 (4.1)	17,299 (98.9)
Male	43,954 (97.5)	4712 (95.9)	189 (1.1)
Race			
White	43,115 (95.6)	4838 (98.4)	17,312 (99.0)
Non-white	936 (2.1)	26 (<1.0)	141 (0.8)
Not reported	1023 (2.3)	52 (1.0)	35 (0.2)
Highest grade completed			
<12 years	3701 (8.2)	146 (3.0)	896 (5.0)
≥12 years	39,455 (87.5)	4592 (93.4)	16,244 (93.0)
Not reported	1918 (4.3)	178 (3.6)	348 (2.0)
Smoking status			
Never	21,869 (48.5)	2285 (46.5)	12,181 (69.6)
Ever	21,922 (48.6)	2536 (51.6)	4766 (27.3)
Not reported	1283 (2.8)	95 (1.9)	541 (3.1)

Results

A total of 8934 (7321 farmer, 532 commercial, 1081 spouse) participants with one or more missing variables were omitted from the analyses, resulting in 45,074 farmer applicators and 4384 commercial applicators retained in the factor analyses (Table 1). For spouses of farmer applicators, we also excluded an additional 13,778 who reported that they had never mixed or applied pesticides, leaving 17,488 (56.1%) in the analysis. Commercial applicators tended to be younger than farmer applicators, and the majority of all cohort members were white and lived in Iowa. The majority of farmer (97.5%) and commercial (95.9%) applicators were male, while the majority of spouses were female (98.9%).

Correlation coefficients were higher for pesticides within the same class (i.e., herbicides, insecticides), ranging from 0.30 to 0.70, and lower or close to zero among pesticides of different classes (data not shown). Results of the factor analyses revealed both consistent patterns of ever/never chemical use across applicator subgroups, as well as patterns that differed among subgroups.

Farmer Applicators

For farmer applicators, three factors (F1–F3) were retained that explained 89% of the total variance in the observed data (Table 2). Variables loading high on factor F1 (i.e., with factor loading scores equal to ± 0.40), included most of the herbicides, two insecticides (phorate, terbufos,), and Iowa. Factor F1 explained 44% of variance in the observed data. Factor F2 explained an additional 31% of the variance, and was comprised of one herbicide (paraquat), four insecticides (aldicarb, carbaryl, diazinon, parathion,), one fumigant (methyl bromide), four fungicides (benomyl, chlorothalonil, mancozeb, metylaxyl), and North Carolina. Variables significant to Factor F3 were two herbicides (2,4,5-T and 2,4,5-TP), six chlorinated insecticides (aldrin, chlordane,

Table 2. Factor analysis results for farmer applicators ($N = 45{,}074$), including 50 pesticides, age, state and gender[a]

		Factor F1	Factor F2	Factor F3
Herbicides	Alachlor	49[b]	12	2
	Atrazine	59[b]	1	0
	Butylate	50[b]	10	9
	Chlorimuron ethyl	48[b]	18	−11
	Cyanazine	54[b]	−10	4
	Dicamba	55[b]	−23	3
	EPTC	43[b]	−7	0
	Glyphosate	31	28	−4
	Imazethapyr	58[b]	−21	−11
	Metolachlor	58[b]	11	−11
	Metribuzin	62[b]	0	5
	Paraquat	14	52[b]	6
	Petroleum oil	44[b]	13	12
	Pendimethalin	46[b]	30	−13
	Trifluralin	60[b]	−1	−2
	2,4-D	51[b]	1	8
	2,4,5 T P	7	11	42[b]
	2,4,5 T	6	0	56[b]
Insecticides	Aldicarb	8	61[b]	−9
	Aldrin	12	−6	63[b]
	Carbaryl	4	44[b]	21
	Carbofuran	32	18	15
	Chlordane	0	19	54[b]
	Chlorpyrifos	34	23	−3
	Coumaphos	11	2	15
	DDVP	21	−3	18
	DDT	−12	10	64[b]
	Diazinon	6	40[b]	26
	Dieldrin	2	0	56[b]
	Fonofos	32	−8	10
	Heptachlor	13	−14	62[b]
	Lindane	17	6	36
	Malathion	31	16	19
	Parathion	7	41[b]	24
	Permethrin (animal)	26	−3	4
	Permethrin (crop)	29	33	−8
	Phorate	40[b]	−2	17
	Terbufos	44[b]	0	1
	Toxaphene	8	28	41[b]
	Trichlorfon	6	9	2
Fumigants	Aluminum phosphide	14	18	14
	Ethylene dibromide	−4	36	20
	Methyl bromide	−11	58[b]	−3
	80/20 mix	3	11	38
Fungicides	Benomyl	−1	61[b]	5
	Captan	17	18	7
	Chlorothalonil	6	54[b]	−12
	Mancozeb	−10	56[b]	9
	Metylaxyl	−4	61[b]	−3
	Ziram	−2	23	18

Table 2. (*Continued*)

		Factor F1	Factor F2	Factor F3
Demographics	Age > 50 years	−28	−13	55[b]
	State = Iowa	46[b]	−66[b]	8
	Gender = male	17	0	2
	Eigenvalue	6.75	4.79	2.23
	% variance explained	0.44	0.31	0.14
	% cumulative variance	0.44	0.75	0.89

[a]For ease of presentation, all values were multiplied by 100 and rounded to the nearest integer.
[b]Indicates factor loading score of ± 0.40 or higher.

DDT, dieldrin, heptachlor, toxaphene), and age greater than 50 years.

Iowa Commercial Applicators

Five factors were retained (C1–C5) that explained 97% of the total variance in the observed data for this subgroup (Table 3). Almost all of the pesticide variables clustered in one of the five factors, and none overlapped. The first two factor patterns for commercial applicators were similar, but not identical to, two of the patterns observed for farmer applicators. Factor C1 included almost all of the herbicides (except for 2,4,5-T and 2,4,5-TP), and one crop insecticide (permethrin). Factor C2 included two herbicides (2,4,5-T and 2,4,5-TP), six chlorinated insecticides (aldrin, chlordane, DDT, dieldrin, heptachlor, toxaphene), and age greater than 50 years. Pesticides significant to Factor C3 included fungicides (benomyl, chlorothalonil, mancozeb, metylaxyl) and residential insect treatments (carbaryl, diazinon, trichlorfon). Insecticides that are often used for controlling livestock pests loaded high on Factor C4, including carbofuran, DDVP, fonofos, permethrin and terbufos. Factor C5 was comprised of one fungicide (ziram), three fumigants: aluminum phosphide, ethylene dibromide, and 80/20 mix, a carbon tetrachloride/carbon disulfide mixture.

Spouses of Farmer Applicators

The factor patterns for spouses (S1–S3) were generally similar to those observed for farmer applicators, and explained 91% of the total variance in the observed data (Table 4). Factor S1 explained 62% of the variance, and included most of the herbicides and four insecticides (carbofuran, chlorpyrifos, fonofos, terbufos). Aldrin, chlordane, DDT, dieldrin, and heptachlor, five chlorinated insecticides, comprised Factor S2. Pesticides significant to Factor S3 were a combination of a fumigant (methyl bromide) and fungicides (benomyl, chlorathalonil, mancozeb, metylaxyl). For spouses, none of the demographic

Table 3. Factor analysis results for commercial applicators ($N = 4384$), including 50 pesticides, age, and gender[a]

		Factor C1	Factor C2	Factor C3	Factor C4	Factor C5
Herbicides	Alachlor	78[b]	0	−12	6	4
	Atrazine	83[b]	2	−12	0	−2
	Butylate	66[b]	13	−6	5	6
	Chlorimuron ethyl	86[b]	−4	−4	−6	6
	Cyanazine	85[b]	0	−12	0	2
	Dicamba	74[b]	−2	24	−9	−7
	EPTC	77[b]	−5	−10	2	9
	Glyphosate	48[b]	−6	34	0	−12
	Imazethapyr	89[b]	−8	−10	−6	5
	Metolachlor	89[b]	−5	−13	−3	4
	Metribuzin	85[b]	4	−10	0	4
	Paraquat	52[b]	12	12	2	5
	Pendimethalin	85[b]	−5	11	−10	0
	Petroleum oil	52[b]	9	8	11	2
	Trifluralin	79[b]	−2	0	0	0
	2,4-D	58[b]	2	29	−6	−15
	2,4,5 T P	11	62[b]	10	−13	−3
	2,4,5 T	12	73[b]	6	−11	−12
Insecticides	Aldicarb	−3	21	19	3	24
	Aldrin	2	77[b]	−12	5	−1
	Carbaryl	19	15	44[b]	12	−7
	Carbofuran	23	8	3	42[b]	−9
	Chlordane	−5	49[b]	19	8	4
	Chlorpyrifos	20	−3	29	33	−7
	Coumaphos	−3	8	−4	27	4
	DDVP	−9	−1	−5	48[b]	19
	DDT	−6	71[b]	−2	−2	−2
	Diazinon	−3	15	46[b]	17	1
	Dieldrin	−7	65[b]	−4	−4	18
	Fonofos	17	2	2	50[b]	−9
	Heptachlor	2	73[b]	−8	7	0
	Lindane	−1	28	13	22	15
	Malathion	31	3	26	21	2
	Parathion	4	29	10	9	17
	Permethrin (animal)	−3	−8	−2	42[b]	11
	Permethrin (crop)	45[b]	−7	10	23	−4
	Phorate	21	24	0	34	0
	Terbufos	22	−2	−1	52[b]	−7
	Toxaphene	2	57[b]	−5	4	14
	Trichlorfon	−6	−7	46[b]	−1	−6
Fumigants	Aluminum phosphide	15	−14	−3	25	53[b]
	Ethylene dibromide	−1	8	6	2	62[b]
	Methyl bromide	−13	−11	2	32	28
	80/20 mix	2	12	−1	15	53[b]
Fungicides	Benomyl	−6	2	69[b]	−10	16
	Captan	−7	−3	29	22	4
	Chlorothalonil	−9	−10	69[b]	−6	−7
	Mancozeb	1	1	58[b]	−11	26
	Metylaxyl	9	1	50[b]	2	19
	Ziram	4	8	16	−17	54[b]
Demographics	Age > 50 years	−8	48[b]	−9	−7	−13
	Gender = male	19	7	−7	−5	−1
	Eigenvalue	12.07	4.99	2.21	1.38	1.09
	% variance explained	0.54	0.22	0.10	0.06	0.05
	% cumulative variance	0.54	0.76	0.86	0.92	0.97

[a]For ease of presentation, all values were multiplied by 100 and rounded to the nearest integer.
[b]Indicates factor loading score of ±0.40 or higher.

variables (age, state, gender) contributed to any of the factors.

As mentioned previously, factors are extracted in order of the proportion of variance accounted for by each factor, and the factor explaining the greatest proportion of variance is extracted first. For both farmer applicators and spouses of farmer applicators, the summary factor that explained most of observed variables was weighted heaviest by herbicide use. The second and third factors derived for each group were similar but differed according to the order in which they were extracted. For farmer applicators, the second summary factor (F2) was weighted by insecticides, methyl bromide and fungicides, while the third factor was weighted by chlorinated pesticides. This order was reversed for spouses.

Additional Analyses for Farmer Applicators

Because farmer applicators provided detailed information concerning farming activities that would be correlated with pesticide use, we performed additional factor analyses to examine whether any of the following would cluster with pesticide use: crops or livestock produced, pesticide application methods, protective equipment generally worn while applying pesticides, and lifestyle characteristics. In this analysis, an additional 3926 subjects were omitted due to missing data for one or more of the variables included in the analysis. The results (Table 5) were similar to what we observed when we included pesticides only (Table 2), with the addition of a fourth summary factor. Factor FF1 was essentially the same as factor F1. In addition to the herbicides and Iowa residence, the following variables contributed to this factor pattern: field corn, soybeans, boom application, in furrow or banded application, and use of chemical gloves. Factor FF2 was also similar to what we observed when evaluating pesticides only (Table 2; F2), with the addition of cotton, peanuts, tobacco, and row fumigation, but with only one insecticide (aldicarb). Significant contributors to Factor FF3 included chlorinated pesticides and age greater than 50

Table 4. Factor analysis results for spouses of farmers ($N = 17,488$), including 50 pesticides, age, state and gender[a]

		Factor S1	Factor S2	Factor S3
Herbicides	Alachlor	70[b]	−1	3
	Atrazine	70[b]	2	1
	Butylate	52[b]	3	2
	Chlorimuron Ethyl	57[b]	−5	3
	Cyanazine	71[b]	1	−5
	Dicamba	69[b]	−5	−6
	EPTC	61[b]	−5	−3
	Glyphosate	22	−2	6
	Imazethapyr	75[b]	−11	−7
	Metolachlor	76[b]	−12	0
	Metribuzin	65[b]	2	−2
	Paraquat	21	4	24
	Pendimethalin	65[b]	−11	12
	Petroleum oil	48[b]	9	5
	Trifluralin	67[b]	−2	−4
	2,4-D	37	14	0
	2,4,5 T P	15	22	2
	2,4,5 T	13	34	−3
Insecticides	Aldicarb	6	1	31
	Aldrin	4	57[b]	−10
	Carbaryl	−11	17	24
	Carbofuran	41[b]	27	7
	Chlordane	−4	46[b]	12
	Chlorpyrifos	43[b]	16	17
	Coumaphos	6	30	1
	DDT	−1	45[b]	9
	DDVP	4	33	−3
	Diazinon	0	19	32
	Dieldrin	−5	52[b]	−7
	Fonofos	43[b]	25	−3
	Heptachlor	5	57[b]	−11
	Lindane	3	33	12
	Malathion	7	26	21
	Parathion	1	22	18
	Permethrin (animal)	6	25	3
	Permethrin (crop)	13	16	18
	Phorate	36	25	−4
	Terbufos	53[b]	16	−2
	Toxaphene	−4	39	6
	Trichlorfon	3	17	8
Fumigants	Aluminum phosphide	7	7	12
	Ethylene dibromide	1	6	21
	Methyl bromide	2	−5	49[b]
	80/20 mix	1	17	7
Fungicides	Benomyl	−2	1	45[b]
	Captan	−1	11	30
	Chlorothalonil	5	−2	42[b]
	Mancozeb	−3	−1	49[b]
	Metylaxyl	7	−4	55[b]
	Ziram	0	3	20
Demographics	Age > 50 years	−8	20	0
	State = Iowa	15	7	−39
	Gender = male	−12	1	−20
	Eigenvalue	8.35	2.37	1.50
	% variance explained	0.62	0.18	0.11
	% cumulative variance	0.62	0.80	0.91

[a]For ease of presentation, all values were multiplied by 100 and rounded to the nearest integer.
[b]Indicates factor loading score of ± 0.40 or higher.

Table 5. Factor analysis results for farmer applicators, including crops, pesticide application methods, protective equipment, 50 pesticides, demographic and lifestyle variables ($N = 41,148$)[a]

		Factor FF1	Factor FF2	Factor FF3	Factor FF4
Crops/ livestock	Field corn	59[b]	−24	−12	0
	Sweet corn	−6	11	−4	22
	Soybeans	66[b]	−8	−12	−14
	Cotton	20	56[b]	−19	−13
	Peanuts	19	54[b]	−18	−14
	Tobacco	−11	61[b]	−14	−4
	Trees	−27	3	8	8
	Strawberries	−10	6	2	16
	Peaches	−13	7	4	11
	Other fruit	−19	16	2	19
	Other vegetables	−1	−4	−10	40[b]
	Grains	5	3	−12	37
	Beef cattle	3	−16	−8	39
	Dairy cattle	−9	−11	−8	23
	Poultry	−4	10	−7	15
	Sheep	3	−8	−2	11
	Eggs	−5	2	−4	15
	Hogs	24	−21	−14	22
Application methods	Aerial	6	7	4	2
	Airblast	−12	10	8	9
	Backpack sprayer	−12	21	12	23
	Boom	43[b]	19	−9	3
	Hand sprayer	18	3	8	28
	In furrow/ banded	48[b]	7	−3	17
	Mist blowing	−5	4	8	28
	Row fumigation	8	52[b]	−6	4
	Pour fumigants	5	14	5	15
	Gas canister	−8	32	4	18

Table 5. (*Continued*)

		Factor FF1	Factor FF2	Factor FF3	Factor FF4
	Powder dusting	−10	18	7	34
	Tablets	8	13	8	24
	Pretreated seeds	28	20	6	28
	Spraying animals	19	−9	0	55[b]
	Dipping animals	4	10	−3	39
	Ear tags	8	−8	−2	52[b]
	Injecting animals	18	−4	−4	54[b]
Protective equipment	Chemical gloves	40[b]	−10	−5	6
	Disposable clothing	−3	5	1	6
	Fabric gloves	−9	8	2	11
	Face shield/goggles	12	−1	2	6
	Respirator/face mask	−16	12	8	12
	None	−14	13	4	−1
Herbicides	Alachlor	47[b]	15	7	−1
	Atrazine	56[b]	4	5	1
	Butylate	48[b]	11	18	−6
	Chlorimuron ethyl	51[b]	21	−4	−7
	Cyanazine	48[b]	−8	7	5
	Dicamba	50[b]	−23	6	4
	EPTC	36	−8	7	3
	Glyphosate	20	25	7	6
	Imazethapyr	58[b]	−18	−5	−10
	Metolachlor	58[b]	16	−4	−8
	Metribuzin	60[b]	0	15	−7
	Paraquat	9	47[b]	14	7
	Petroleum oil	37	11	17	13
	Pendimethalin	49[b]	36	−5	−8
	Trifluralin	59[b]	2	8	−12
	2,4-D	45[b]	−1	14	4
	2,4,5-T	6	−6	56[b]	−1
	2,4,5-TP	5	4	45[b]	2
Insecticides	Aldicarb	16	68[b]	−5	−11
	Aldrin	18	−8	63[b]	−13
	Carbaryl	−4	36	28	12
	Carbofuran	26	17	19	8
	Chlordane	−2	10	57[b]	2
	Chlorpyrifos	28	23	0	14
	Coumaphos	0	−3	11	30
	DDT	−8	5	64[b]	−10
	DDVP	11	−7	16	24
	Diazinon	−4	30	34	14
	Dieldrin	4	−6	57[b]	−6
	Fonofos	28	−7	9	7
	Heptachlor	16	−17	65[b]	−5
	Lindane	8	−2	38	17
	Malathion	24	10	25	13
	Parathion	4	35	29	7
	Permethrin (animal)	13	−6	0	35
	Permethrin (crop)	22	32	0	7
	Phorate	42[b]	1	17	−1
	Terbufos	42[b]	3	1	9
	Trichlorfon	2	8	5	3
	Toxaphene	11	23	44[b]	−4
Fumigants	Aluminum phosphide	12	12	19	4
	Ethylene dibromide	−5	29	25	3
	Methyl bromide	−16	58[b]	2	6
	80/20 mix	2	4	40[b]	2
Fungicides	Benomyl	−3	54[b]	16	−2
	Captan	6	11	13	16
	Chlorothalonil	7	58[b]	−7	−4
	Mancozeb	−15	48[b]	19	3
	Metalaxyl	−4	61[b]	5	1
	Ziram	−4	13	24	−1
Demographics	State = Iowa	47[b]	−67[b]	2	1
	Age > 50 years	−18	−16	55[b]	−23
	Gender = male	21	2	2	−3
	Race	7	−10	6	9
	Education	15	−2	−4	13
Lifestyle	Ever smoke	−5	7	14	−9
	Alcohol intake	11	−3	−4	2
	Fruit consumption	−4	−11	17	9
	Vegetable consumption	−2	3	11	15
	Eigenvalue	8.41	6.85	2.94	2.42
	% variance explained	0.30	0.24	0.10	0.08
	% cumulative variance	0.30	0.54	0.64	0.73

[a]For ease of presentation, all values were multiplied by 100 and rounded to the nearest integer.
[b]Indicates factor loading score of ±0.40 or higher.

years, with the addition of the fumigant 80/20 mix. This is also similar to Factor F3 observed for farmer applicators (Table 2) and factor S2 observed for spouses (Table 4). The fourth factor pattern included other vegetables, spraying of animals, use of ear tags, and injecting animals. None of the lifestyle variables achieved factor loading scores of ±0.40 or higher in any of the factors.

Discussion

In this exploratory analysis, factor analysis was a simple and relatively quick tool for examining the complex relationships among a large set of exposure variables, and summarizing 50 pesticide exposure variables into smaller groups of exposure patterns that varied among the three types of pesticide applicators in this cohort. The variables considered to be significant to each factor (i.e., variables with factor loading scores of ± 0.40 or higher) were all correlated to some degree, because some of the pesticides in each factor were likely to have been used simultaneously. The correlations were also supported by an understanding of pesticide use over time, since changes in pesticide formulations may have led to changes in recommendations for use, or certain pesticides may have been taken off the market.

The factors derived for farmer applicators identified three distinct patterns of pesticide application activities: Iowa agriculture (soybeans, corn) and herbicide use (F1); North Carolina agriculture (cotton, peanuts, tobacco), which requires more intensive insecticide and fumigant applications (F2); and use of chlorinated insecticides, an exposure pattern more typical of older farmers (F3). These chlorinated insecticides are no longer marketed for use in the United States (California EPA, 2002). Farmers who were 50 years of age or older at the time of enrollment were more likely to have greater exposure to these pesticides that were on the market during the 1970s and 1980s, when they have been in their 20s and 30s. These three factor patterns were the same for both the pesticide-only analysis and analysis including crop-type and other variables.

The additional variables that clustered with the herbicides in Factor FF1 were also related to Iowa agriculture and herbicide applications (i.e., field corn, soybeans, boom application, in furrow or banded application), while the additional variables that clustered with the pesticides in Factor FF2 are typical of North Carolina agriculture (i.e., peanuts, cotton, tobacco, and row fumigation). Factor FF3 remained virtually unchanged; none of the additional farming variables patterned with chlorinated pesticides. A fourth factor, which did not include any of the pesticides, was suggestive of livestock production (i.e., other vegetables, animal pest control application methods). Two additional variables (beef cattle and dipping animals) were most likely important to this fourth factor, although the factor loading score for each of these variables was 0.39. None of the lifestyle factors that we were able to include, and known to be related to cancer, heart disease, and other types of health problems, were significant components of the resulting factor patterns. We observed no relationship between pesticide or farm-related exposures and lifestyle characteristics, such as smoking. In this cohort, the greatest amount of heterogeneity seemed to be due to pesticide use, indicated by the fact that pesticides were the greatest contributors to the resulting exposure patterns.

There was some overlap between the factor patterns observed for farmer applicators and those observed for commercial applicators. The five factors derived for commercial applicators may be described as follows: Iowa agriculture and herbicide use (C1); chlorinated pesticides no longer marketed for use in the US (C2); residential pesticide treatments (C3); treatment of livestock (C4); and fumigation (C5). It is not surprising that factor C1, which explains the majority of the variance in the observed data, represents Iowa agriculture, since all of the commercial applicators were from Iowa. The factor patterns observed for this group of applicators suggest a broader range of application activities compared to farmer applicators, and therefore greater potential pesticide exposures. These activities should be considered in etiologic studies. Although farmer and commercial applicators may receive similar pesticide exposures when applying herbicides or insecticides to crops, commercial applicators may differ from farmer applicators with respect to the type of pesticides they apply, the number of spray jobs performed in a day, the range of pesticides applied in a day, and the frequency with which other tasks are performed, such as mixing and loading, and performing maintenance on spray rigs (Hines et al., 2001).

Factor patterns observed for spouses of applicators were similar to those observed among farmer applicators (i.e., their husbands), and may be described as Iowa agriculture and herbicide use (Factor S1); chlorinated pesticides no longer marketed for use in the US (Factor S2); and fumigant and fungicide use (Factor S3). Although the spouses were not the licensed pesticide applicators, they may engage in similar pesticide application activities as the farmer applicators by assisting with field work, or performing additional application activities such as pest control in the home, garden, and on pets. Given that the majority of spouses live in Iowa and share a similar age distribution as their farmer husbands, use of chlorinated pesticides (Factor S2, related to age) weights heavier than the pattern of pesticide use associated with North Carolina (Factor S3), and explains why among spouses, unlike their farmer husbands, use of chlorinated pesticides explains a greater proportion of variance than use of fumigants and fungicides.

In order to compare the factor patterns across the three types of applicators, we were limited to ever/never response data. Although farmer and commercial applicators provided pesticide-specific information concerning number of days per year and number of years applied, spouses were not asked to provide such quantitative pesticide exposure information. In addition, only 40% of farmer and commercial applicators ($N = 24{,}365$) provided quantitative exposure data for all 50 pesticides. Despite this limitation, the factor patterns we observed for each applicator group were consistent with the types of farming activities in which they would most likely be engaged. In addition, because farmers and their spouses engage in a variety of tasks to maintain their farms and equipment, it may be necessary to consider nonpesticide exposures when investigating exposure-disease associations, such as the use of solvents, paint, or exposure to welding fumes (Coble et al., 2002).

The factors observed for each type of applicator have been used as independent variables in an epidemiologic analysis of the association between exposure to various pesticides and the risk of prostate cancer (Alavanja et al., 2003). To do this, the factor loading scores for each of the variables in the analysis and the subjects' responses to each of those variables (e.g., 0 = No, 1 = Yes) were used in an algorithm to calculate a *factor-based score* for each subject, for each factor. These scores represent each subject's relative standing with respect to how closely they "resemble" each factor (Kleinbaum and Kupper, 1978), and may be used to divide subjects into low, medium, and high exposure.

If a significant proportion of variables that heavily weight a summary factor are independently related to a certain health outcome, a quantitative association may be observed between that factor and the health outcome of interest. If only one or a small number of variables that weight a summary factor are associated with the health outcome of interest, then factor-based scores may not show a strong, quantitative association with that particular health outcome. In addition, the variables that significantly contribute to each factor may help guide traditional multivariate analyses by suggesting potential interaction between exposure variables.

Our results indicate that factor analysis was a suitable method for characterizing patterns of exposure to the pesticides among the licensed pesticide applicators and their spouses in the AHS cohort, and should be considered for similar kinds of epidemiologic analyses. The resulting factor patterns were clearly interpretable and logical for the study population, and completely data driven. The next step may be to further explore these patterns by using quantitative (e.g., continuous) data such as lifetime days of pesticide use, which is being collected from all three subgroups (commercial applicators, farmers, spouses of farmers) during Phase II of the study. The patterns of exposure observed in the present study may be used to guide more traditional analyses of pesticide exposure and risk for various health outcomes among the subgroups of applicators in this cohort.

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